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MAGNETIC TUNNEL JUNCTION DEVICE WITH ETCH STOP LAYER AND DUAL- DAMASCENE CONDUCTOR

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MAGNETIC TUNNEL JUNCTION DEVICE WITH ETCH STOP LAYER AND DUAL- DAMASCENE CONDUCTOR

FIELD OF THE INVENTION

The present invention relates generally to a method of making a magnetic tunnel junction device. More specifically, the present invention relates to a method of making a magnetic tunnel junction device with a self-aligned via and a dual damascene conductor that is in contact with an etch stop layer that prevents chemical erosion of one or more layers of a magnetic material of the magnetic tunnel junction device during an etching process.

BACKGROUND OF THE INVENTION

An magnetoresistance random access memory (MRAM) includes an array of memory cells. Each memory cell is a magnetic tunnel junction device. The magnetic tunnel junction device operates on the principles of spin tunneling. There are several types of magnetic tunnel junction devices including two prominent types, tunneling magnetoresistance (TMR) and giant magnetoresistance (GMR). Both types of devices comprise several layers of thin film materials and include a first layer of magnetic material in which a magnetization is alterable and a second layer of magnetic material in which a magnetization is fixed or "pinned" in a predetermined direction. The first layer is commonly referred to as a data layer or a sense layer; whereas, the second layer is commonly referred to as a reference layer or a pinned layer. The data layer and the reference layer are separated by a very thin tunnel barrier layer. In a TMR device, the tunnel barrier layer is a thin film of a dielectric material (e.g. silicon oxide **SiO_2**). In contrast, in a GMR device, the tunnel barrier layer is a thin film of an electrically conductive material (e.g. copper **Cu**).

Electrically conductive traces, commonly referred to as word lines and bit lines, or collectively as write lines, are routed across the array of memory cells with a memory

cell positioned at an intersection of a word line and a bit line. The word lines can extend along rows of the array and the bit lines can extend along columns of the array, or vice-versa. A single word line and a single bit line are selected and operate in combination to switch the alterable orientation of magnetization in the memory cell located at the intersection of the selected word and bit lines. A current flows through the selected word and bit lines and generates magnetic fields that collectively act on the alterable orientation of magnetization to cause it to switch (i.e. flip) from a current state (i.e. a logic zero "0") to a new state (i.e. a logic "1"). Typically, the alterable orientation of magnetization is aligned with an easy axis of the data layer and the magnetic field causes the alterable orientation of magnetization to flip from an orientation that is parallel with the pinned orientation of the reference layer or to an orientation that is anti-parallel to the pinned orientation of the reference layer. The parallel and anti-parallel orientations can represent the logic states of "0" and "1" respectively, or vice-versa.

Because the layers of material that comprise the magnetic tunnel junction device are very thin layers of material (e.g. on the order of about 15.0 nm or less), the manufacturing of defect free magnetic tunnel junction devices can be quite difficult. Those defects can include variations in magnetic switching characteristics among memory cells in the same array, defects in the tunnel barrier layer, and defects in the layer(s) of magnetic materials that comprise the data layer and/or the reference layer. Additionally, magnetic materials are also used for anti-ferromagnetic layers, cap layers, seed layers, and pinning layers, etc.

In **FIGS. 1a** and **1b**, a prior magnetic tunnel junction device **200** can include a bottom conductor **213** that can be a bit line, a seed layer **211** (e.g. made from tantalum **Ta**), a pinned layer **209** of a magnetic material (e.g. made from nickel iron **NiFe**) and including a pinned orientation of magnetization $\mathbf{m_1}$, a tunnel barrier layer **207** (e.g made from aluminum oxide $\mathbf{Al_2O_3}$ for a TMR device), a data layer **205** of a magnetic material (e.g. made from nickel iron cobalt **NiFeCo**) and including an alterable orientation of magnetization $\mathbf{m_2}$, a cap layer **203** (e.g. made from tantalum **Ta**), and a top conductor **201** that can be a word line.

One disadvantage to prior methods for manufacturing the magnetic tunnel junction device **200** is that many processing steps are required. As a result, yield can be compromised by any of those steps. For example, the process for forming the top conductor **201** can require several processing steps that can include: in a first step, forming a via in a dielectric layer (not shown) that extends to the data layer **205**; filling the via with an electrically conductive material; and then in a second step, depositing another electrically conductive material to form the top conductor **201**. Generally, more processing steps increases the risk that one of those steps will introduce a defect that will render the magnetic tunnel junction device **200** inoperable, with a resulting decrease in yield.

Another disadvantage to prior methods for manufacturing the magnetic tunnel junction device **200** is that the chemicals used during some of the processing steps can chemically attack or erode the magnetic materials that are used to form some of the thin film layers of the magnetic tunnel junction device **200**. For example, the above mentioned via can be formed by using a plasma or wet etch process **P** to remove a layer of dielectric material that covers the cap layer **203**. Because the layers of material are very thin, during an over etch step, etch materials that are fluoride (**F**) based can permeate the cap layer **203** and the layers below it to chemically erode **E** the magnetic materials in the data layer **205**, the reference layer **209**, and any other layers that include magnetic materials such as nickel (**Ni**), iron (**Fe**), and cobalt (**Co**), for example.

Consequently, there is a need for a method of making a magnetic tunnel junction device that reduces the number of processing steps. There is also a need for a method of making a magnetic tunnel junction device that protects the layers of magnetic material from erosion caused by chemicals used in the processing of the magnetic tunnel junction device.

SUMMARY OF THE INVENTION

The present invention is embodied in a method of making a magnetic tunnel junction device. The magnetic tunnel junction device solves the aforementioned problems associated with chemical erosion of the plurality of layers of the magnetic material that are part of the magnetic tunnel junction stack by forming an etch stop layer made from a first electrically conductive material on the magnetic tunnel junction stack. The plurality of layers of magnetic material are positioned below the etch stop layer. The etch stop layer serves as a barrier that protects the underlying layers of magnetic material during subsequent etching steps. Chemicals contained in the etchant material, such as fluorine (**F**), that can chemically erode the magnetic materials, are prevented from attacking the magnetic materials by the barrier imposed by the etch stop layer.

Moreover, the aforementioned problems caused by additional process steps and their potential for creating defects in the magnetic tunnel junction device are solved by a dual-damascene conductor that includes a via and a top conductor that are homogeneously formed in a single process step. Consequently, fewer process steps are required to manufacture the magnetic tunnel junction device and yield can be increased because fewer process steps are required.

Other aspects and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1a is a cross-sectional view depicting a prior magnetic tunnel junction device.

FIG. 1b is a cross-sectional view depicting erosion of layers of magnetic material in a prior magnetic tunnel junction device during an etching step.

FIG. 2 is a flow diagram depicting a method of making a magnetic tunnel junction device.

FIG. 3 is a cross-sectional view depicting a discrete magnetic tunnel junction stack including an etch stop layer.

FIG. 4 is a cross-sectional view depicting a magnetic tunnel junction device including a dual-damascene conductor and an etch stop layer.

FIG. 5 is a cross-sectional view depicting a magnetic tunnel junction stack.

FIG. 6a is a cross-sectional view depicting a patterning of a magnetic tunnel junction stack.

FIG. 6b is a cross-sectional view depicting an etching of a magnetic tunnel junction stack.

FIG. 7 is a cross-sectional view depicting a discrete magnetic tunnel junction stack including an etch stop layer and a plurality of thin film layers.

FIG. 8 is a cross-sectional view depicting a dielectric layer formed on the the discrete magnetic tunnel junction stack of **FIG. 7**.

FIG. 9 is a cross-sectional view depicting a planarized dielectric layer.

FIG. 10a and **FIG. 10b** are a cross-sectional views depicting an etching of a first mask layer.

FIG. 11 is a cross-sectional view depicting a second electrically conductive material formed on a dielectric layer and in a self-aligned via.

FIG. 12 is a cross-sectional view depicting a patterning and an etching of a second electrically conductive material.

FIG. 13 is a cross-sectional view depicting a magnetic tunnel junction device including a dual-damascene conductor and an etch stop layer.

FIG. 14 is a cross-sectional view depicting layers of magnetic materials that are protected from damage due to erosion by an etch stop layer.

FIG. 15 is a top plan view depicting an array of magnetic tunnel junction devices.

FIG. 16 is a cross-sectional view along line **A-A** of **FIG. 15**.

DETAILED DESCRIPTION

As shown in the drawings for purpose of illustration, the present invention is embodied in a method of making a magnetic tunnel junction device. In **FIG. 2**, the method includes forming **70** a magnetic tunnel junction stack, forming **71** an etch stop layer of a first electrically conductive material on the magnetic tunnel junction stack, forming **72** a first mask layer on the etch stop layer, and patterning **73** the first mask layer. A discrete magnetic tunnel junction stack is formed **74** by etching the magnetic tunnel junction stack, then a dielectric layer is formed **75** on the discrete magnetic tunnel junction stack followed by a planarizing **76** of the dielectric layer. A self-aligned via is formed **77** by etching the first mask layer. A second electrically conductive material is deposited **78** in the self-aligned via and on the dielectric layer. The second electrically conductive material is then patterned **79**. A dual-damascene conductor is formed **80** by etching the second electrically conductive material.

In **FIG. 3**, a discrete magnetic tunnel junction stack **20** can include a plurality of thin film layers of materials that are well know in the MRAM art. Those layers include but are not limited to a reference layer **17** (also called a pinned layer) made from a magnetic material and including a pinned orientation of magnetization $\mathbf{M_1}$, a tunnel barrier layer **15** that can be a dielectric material for a TMR device or an electrically conductive material for a GMR device, and a data layer **13** (also called a sense layer) made from a magnetic material and including an alterable orientation of magnetization $\mathbf{M_2}$. The discrete magnetic tunnel junction stack **20** also includes an etch stop layer **12** made from a first electrically conductive material as will be described below and an electrically conductive material **21** that can be a bottom conductor or electrode, for example. Unless otherwise noted, the thin film layers (**13, 15, 17**) of the magnetic tunnel junction stack **20** will be collectively denoted as the layers **30**. The layers **30** include a top portion **30t**, a bottom portion **30b**, and side portions **30s**. For purposes of illustration, other layers that can be included in the layers **30** are not depicted in **FIG. 3**. Those layers include but are not limited to cap layers, seed layers, pinning layers, anti-ferromagnet layers, and artificial anti-ferromagnetic layers, just to name a few.

Although the etch stop layer **12** is depicted in contact with the data layer **13**, the method of the present invention includes forming the etch stop layer **12** on any suitable layer positioned at the top portion **30t** of the thin film layers **30** so that during an etching process $\mathbf{P_E}$, the underlying layers of magnetic material in the thin film layers **30** are not chemically eroded by chemicals in an etchant material used in the etching process $\mathbf{P_E}$. Accordingly, the etch stop layer **12** serves as a barrier that prevents the chemical erosion of the plurality of layers of a magnetic material positioned below the etch stop layer **12** in the discrete magnetic tunnel junction stack **20**. Consequently, after the etching process $\mathbf{P_E}$, the thin film layers **30**, particularly those layers that are made from a magnetic material, are not damaged **D** due to chemical erosion.

In **FIG. 4**, a magnetic tunnel junction device **10** fabricated according to the method depicted in **FIG.2**, includes a dual-damascene conductor **11** that is formed on the discrete magnetic tunnel junction stack **20** and is in contact with the etch stop layer **12**. The etch stop layer **12** is in contact with the top portion **30t** of the thin film layers **30**. The electrically conductive material **21** is in electrical communication with the bottom portion **30b** of the thin film layers **30** and serves as a bottom conductor (also denoted as **21**). The bottom conductor **21** can be in direct contact with the bottom portion **30b** or can be in electrical communication with the bottom portion **30b** through an intermediate structure such as a via or the like, for example. As will be described below, the dual-damascene conductor **11** includes a first portion **11v** that fills a self-aligned via (not shown) and a second portion **11c** that is in contact with a substantially planar surface of a dielectric material (not shown). The first and second portions (**11v, 11c**) are homogeneously formed with each other.

In **FIG. 5** and referring to the above mentioned process as depicted in **FIG. 2**, at a stage **70**, a magnetic tunnel junction stack **60** is formed by depositing a plurality of layers of thin film materials in a process order $\mathbf{d_O}$. The processes and the materials used to form those layers of thin film materials are well understood in the

microelectronics art. The magnetic tunnel junction stack **60** can include a substrate **50** that can be a semiconductor material, a silicon substrate, or a silicon wafer, for example. A dielectric layer **51** can be formed on the substrate **50**. Suitable materials for the dielectric layer **51** include but are not limited to silicon oxide (SiO_2), for example. An electrically conductive material **21** can be formed on the dielectric layer **51** and can be a bottom conductor or an electrode that serves as a word line or bit line in an MRAM array. Suitable materials for the bottom conductor **21** include but are not limited to aluminum (**Al**) and tungsten (**W**), for example.

The other thin film layers in the magnetic tunnel junction stack **60** include but are not limited to: a reference layer **17** that can be made from nickel iron (**NiFe**) or alloys of those materials; a tunnel barrier layer **15** that can be made from aluminum oxide (Al_2O_3) or silicon oxide (SiO_2), and a data layer **13** that can be made from nickel iron cobalt (**NiFeCo**) or alloys of those materials. Examples of other layers that can be included in the magnetic tunnel junction stack **60** include a seed layer and a cap layer made from tantalum (**Ta**), a manganese iron (**MnFe**) AF pinning layer, just to name a few.

Deposition processes that are well known in the microelectronics art can be used to deposit the layers in the magnetic tunnel junction stack **60**. For example, physical vapor deposition (PVD), plasma enhanced chemical vapor deposition (PECVD), and sputtering are deposition processes that can be used to form the aforementioned layers. PVD can include thermal evaporation and sputtering.

In **FIG. 5**, at a stage **71**, an etch stop layer **12** is formed on the uppermost layer of the magnetic tunnel junction stack **60**. Although **FIG. 5** depicts the data layer **13** as the uppermost layer, the method is not limited to the arrangement of layers depicted herein. As an example, the uppermost layer of the magnetic tunnel junction stack **60** can be the reference layer **17** instead of the data layer **13**. The etch stop layer **12** is made from a first electrically conductive material including but not limited to aluminum (**Al**) and alloys of aluminum.

In **FIGS. 6a**, at a stage **72**, a first mask layer **25** is formed on the etch stop layer **12**. The first mask layer **25** can be a material including but not limited to a photoresist material. At a stage **73**, the first mask layer **25** is patterned. A photolithographic processes can be used to expose the first mask layer **25** with light **L** through a mask (not shown) so that the exposed portion is resistant to a material used to develop the photoresist.

In **FIGS. 6b** and **7**, at a stage **74**, the magnetic tunnel junction stack **60** is etched to remove excess portions (see dashed lines **S**) of the magnetic tunnel junction stack **60** to form a discrete magnetic tunnel junction stack **20**. Exposed portions of the magnetic tunnel junction stack **60** are removed by an etch material that selectively removes the layers of the magnetic tunnel junction stack **60** that are not covered by a remaining portion (denoted as **25p**) of the first mask layer **25** (i.e. on either side of the dashed lines **S**) to form the discrete magnetic tunnel junction stack **20**. As described above, those portions of the magnetic tunnel junction stack **20** that include one or more layers of a magnetic material that will be protected against erosion by the etch stop layer **12** are collectively denoted as the layers **30**.

In **FIG. 8**, at a stage **75**, a dielectric layer **31** is formed on the discrete magnetic tunnel junction stack **20** and completely covers the discrete magnetic tunnel junction stack **20**. Suitable materials for the dielectric layer **31** include but are not limited to silicon oxide (**SiO_2**) and silicon nitride (**Si_3N_4**). At a stage **76**, the dielectric layer **31** is planarized until the dielectric layer **31** and the first mask layer **25p** form a substantially planar surface (i.e. planarized along a dashed line **f-f**).

In **FIG. 9**, after the planarization, an upper surface **31s** of the dielectric layer **31** and an upper surface **25s** of the first mask layer **25p** are substantially planar and are substantially flush with each other. For example, a process such as chemical mechanical planarization (CMP) can be used to planarize the first mask layer **25p** and the dielectric layer **31**.

In **FIG. 10a**, at a stage **77**, the first mask layer **25p** is etched by an etch process $\mathbf{P_E}$ that selectively dissolves (i.e. removes) the first mask layer **25p**. In **FIG. 10b**, the etching process $\mathbf{P_E}$ is continued until the first mask layer **25p** is completely dissolved and a self-aligned via **33** is formed in the dielectric layer **31**. The self-aligned via **33** extends all the way to the etch stop layer **12**. The etch material used in the etch process $\mathbf{P_E}$ is not selective to the material of the etch stop layer **12** such that the etch stop layer **12** serves as a penetration barrier (see dashed arrows $\mathbf{E_R}$) that protects the layers of magnetic material in the layers **30** that are positioned below the etch stop layer **12** from damage **D** that can be caused by chemical erosion.

The etch process $\mathbf{P_E}$ can be a plasma etch process or a wet etch process and an etchant material used in the etch process $\mathbf{P_E}$ can include the chemical fluorine (**F**). Fluorine (**F**) can chemically react with and erode the layers magnetic materials in the layers **30**. For example, it is well understood in the MRAM art that a fluorine (**F**) based plasma etch can erode magnetic materials including but not limited to nickel (**Ni**), iron (**Fe**) and cobalt (**Co**). Because the data layer **13** and the reference layer **17** can include one or more of those materials and alloys of those materials, the etch stop layer **12** prevents chemical erosion of the nickel (**Ni**), the iron (**Fe**), and the cobalt (**Co**). The etch material can be a fluorine containing gas including but not limited to $\mathbf{CF_4}$, $\mathbf{CHF_3}$, $\mathbf{C_4F_8}$, and $\mathbf{SF_6}$. Additionally, for a plasma etch process, the etch material (i.e. the etch gas) can include oxygen ($\mathbf{O_2}$) and fluorine (**F**) alone or in combination with other compounds as described above.

In **FIG. 11**, at a stage **78**, a second electrically conductive material **11a** is deposited on the dielectric layer **31**. Preferably, the deposition continues until the second electrically conductive material **11a** completely fills the self-aligned via **33** (i.e. the self-aligned via **33** is completely filled in) and the second electrically conductive material **11a** extends outward of the upper surface **31s** by a predetermined distance $\mathbf{t_C}$ (i.e. by a thickness $\mathbf{t_C}$).

In **FIG. 12**, at a stage **79**, the second electrically conductive material **11a** is patterned. For instance, a photolithographic process and a photoresist material **35** can be used to pattern the second electrically conductive material **11a**. After the pattern is developed, a portion of the photoresist material **35** remains and serves as an etch mask. At a stage **80**, the second electrically conductive material **11a** is etched to define a dual-damascene conductor **11**. The dual-damascene conductor **11** is in contact with the etch stop layer **12**. Suitable materials for the dual-damascene conductor **11** and the bottom conductor **21** include but are not limited to aluminum (**Al**), alloys of aluminum, tungsten (**W**), alloys of tungsten, copper (**Cu**), and alloys of copper.

In **FIG. 13**, the dual-damascene conductor **11** includes a first portion **11v** and a second portion **11c**. The first portion **11v** is a via that is positioned in the self-aligned via **33**. The first portion **11v** completely fills the self-aligned via **33** and is in contact with the etch stop layer **12**. The second portion **11c** is a top conductor that is in contact with the substantially planar surface **31s** of the first dielectric material **31** and extends outward of the substantially planar surface **31s**. The top conductor **11c** can extend outward of the upper surface **31s** by the predetermined distance t_C. Collectively, the dual-damascene conductor **11** and the bottom conductor **21** can be referred to as write lines.

The method of the present invention allows the via **11v** for the self-aligned via **33** and the top conductor **11c** that will serve as one of the electrodes for the magnetic tunnel junction device **10** to be a homogeneously formed dual-damascene conductor **11** that are deposited in one step instead of two or more steps, thereby reducing the number of process steps.

As was described above, the order of the layers **30** in the discrete magnetic tunnel junction stack **20** need not be in the order depicted in **FIGS. 7**, **13** and **14**. As an example, the data layer **13** can be in contact with the bottom conductor **21** and the reference layer **17** can be in contact with the etch stop layer **12**, with the tunnel barrier

layer **15** positioned between the data and reference layers (**13, 17**). As another example, a cap layer (not shown) can be positioned at the top portion **30** and in contact with the etch stop layer **12** and a seed layer (not shown) can be positioned at the bottom portion **30b**.

Accordingly, in **FIG. 13**, the bottom conductor **21** is in electrical communication with a bottom portion **30b** of the layers **30** and the etch stop layer **12** is in contact with a top portion **30t** of the layers **30**. The data and reference layers (**13, 17**), the tunnel barrier layer **15**, and any of the other layers that comprise the layers in **30** (e.g. cap layers, seed layers, etc.) will be positioned between the bottom conductor **21** and the etch stop layer **12** in whatever logical order is dictated by the magnetic tunnel junction topology.

In **FIGS. 15** and **16**, the dual-damascene conductor **11** can be a row conductor **R** and the bottom conductor **21** can be a column conductor **C**, or vice-versa, in an array **100** that includes a plurality of the magnetic tunnel junction devices **10**. The array **100** can be a MRAM used to store and retrieve data written to the plurality of magnetic tunnel junction devices **10**. The dual-damascene conductor **11** is in contact with the etch stop layers **12** of the magnetic tunnel junction devices **10** in each of the rows **R**. The dual-damascene conductor **11** is aligned with a row direction $\mathbf{R_D}$ (see **FIGS. 15** and **16**) of the array **100**. Similarly, the column conductor **C** is in electrical communication with one of the thin film layers **30** (e.g. the reference layer **17**) of the magnetic tunnel junction devices **10** in each columns **C** and the column conductor **C** is aligned along a column direction $\mathbf{C_D}$ (see **FIG. 15**) of the array **100**.

Each of the magnetic tunnel junction devices **10** is positioned between an intersection of the row and column conductors (**R, C**) as depicted by the dashed lines **10**. Typically, the row and column conductors (**R, C**) cross the magnetic tunnel junction devices **10** at substantially right angles to each other. Accordingly, the row and column conductors (**R, C**) define the rows and columns of the array **100** and the magnetic tunnel junction devices **10** are positioned in the rows **R** and columns **C** of the array **100**.

The alterable orientation of magnetization $\mathbf{M_2}$ in the data layer **13** is rotated (i.e. flipped) by passing currents (not shown) of sufficient magnitude through a selected row and column conductor (**R, C**) so that magnetic fields generated by those currents cooperatively combine to flip the alterable orientation of magnetization $\mathbf{M_2}$.

Although several embodiments of the present invention have been disclosed and illustrated, the invention is not limited to the specific forms or arrangements of parts so described and illustrated. The invention is only limited by the claims.